

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Spatial and Temporal Scales of Precipitating Tropical Cloud Systems

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requirements for the degree Doctor of Philosophy

in

Oceanography

By

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*for Erin*

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## LIST OF SYMBOLS

$B_\lambda$	blackbody emission ( $\text{W m}^{-2} \text{str}^{-1} \text{m}^{-1}$ )
$C$	speed of light ( $2.998 \times 10^8 \text{ m s}^{-1}$ )
$C_l$	longwave cloud radiative forcing ( $\text{W m}^{-2}$ )
$C_s$	shortwave cloud radiative forcing ( $\text{W m}^{-2}$ )
$\dot{E}$	evaporation rate ( $\text{kg kg}^{-1} \text{s}^{-1}$ )
$\dot{E}$	evaporation rate ( $\text{kg m}^{-2} \text{s}^{-1}$ )
$F$	longwave flux at top-of-atmosphere ( $\text{W m}^{-2}$ )
$F_{clr}$	clear-sky longwave flux at top-of-atmosphere ( $\text{W m}^{-2}$ )
$F_c$	grid cell fraction containing cloud
$F_p$	grid cell fraction containing precipitation
$F^{cp}$	grid cell fraction containing cloud and precipitation
$f_{240K}$	fraction of cloud area with IR brightness temperature less than 240K
$G$	coefficient for infrared rain estimate ( $\text{mm hr}^{-1}$ )
$h$	Planck constant ( $6.626 \times 10^{-34} \text{ J s}$ )
$I$	radiant intensity ( $\text{W m}^{-2} \text{str}^{-1} \text{m}^{-1}$ )
$k$	Boltzmann constant ( $1.381 \times 10^{-23} \text{ J K}^{-1}$ )
$k_E$	coefficient of rain evaporation
$L$	condensed water amount in grid cell ( $\text{kg m}^{-2}$ )
$L_c$	condensed water amount from convection ( $\text{kg m}^{-2}$ )
$L_s$	condensed water amount from stable condensation ( $\text{kg m}^{-2}$ )
$L_v$	latent heat of vaporization ( $\text{J kg}^{-1}$ )
$LH$	latent heating and latent heat flux ( $\text{W m}^{-2}$ )
$n$	aerosol mixing ratio ( $\text{kg kg}^{-1}$ )
$\dot{P}$	production rate of precipitating water in grid cell ( $\text{kg m}^{-2} \text{s}^{-1}$ )
$\dot{Q}$	net production rate of precipitating water in grid cell ( $\dot{P} - \dot{E}$ ; $\text{kg m}^{-2} \text{s}^{-1}$ )
$\dot{Q}_c$	net production rate of precipitating water from convection ( $\text{kg m}^{-2} \text{s}^{-1}$ )
$\dot{Q}_{sc}$	net production rate of precipitating water from stable condensation ( $\text{kg m}^{-2} \text{s}^{-1}$ )
$RH$	relative humidity
$R$	rate of production of precipitation ( $\text{kg kg}^{-1} \text{s}^{-1}$ )
$R_s$	surface rain rate ( $\text{mm hr}^{-1}$ )
$S^s$	solar flux ( $\text{W m}^{-2}$ ), also radiant source term ( $\text{W m}^{-2} \text{str}^{-1} \text{m}^{-1}$ )
$SH$	sensible heat flux ( $\text{W m}^{-2}$ )
$T$	temperature (K)
$T_{IR}$	METEOSAT-5 infrared window channel brightness temperature (K)
$T_{wv}$	METEOSAT-5 water vapor channel brightness temperature (K)
$\alpha$	albedo, also extinction coefficient ( $\text{m}^{-1}$ )
$\alpha_{clr}$	clear-sky albedo

$\lambda$	wavelength
$\rho_w$	density of water ( $\text{kg m}^{-3}$ )
CCM3	Community Climate Model version 3
CEPEX	Central Equatorial Pacific Experiment
CERES	Clouds and the Earth's Radiant Energy System
CRF	cloud radiative forcing
ERBE	Earth Radiation Budget Experiment
GATE	Global Atmospheric Research Program Tropical Experiment
GCM	general circulation model
INDOEX	Indian Ocean Experiment
IR	infrared
ITCZ	Inter-tropical Convergence Zone
MATCH	Model for Atmospheric Transport and Chemistry
MCS	mesoscale convective system
MPF	mesoscale precipitating feature
NCAR	National Center for Atmospheric Research
SSM/I	Special Sensor Microwave Imager
TOA	top-of-atmosphere
TRMM	Tropical Rainfall Measuring Mission
TMI	TRMM Microwave Imager
WV	water vapor



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## ABSTRACT OF THE DISSERTATION

### Spatial and Temporal Scales of Precipitating Tropical Cloud Systems

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Doctor of Philosophy in Oceanography

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Professor V. Ramanathan, Chair

Precipitation, radiative forcing, and aerosol scavenging in tropical cloud systems over the wintertime Indian Ocean are examined in satellite observations and global atmospheric simulations. Measurements of surface rain rate and top-of-atmosphere radiative fluxes from the TRMM satellite, as well as brightness temperature measurements from the METEOSAT-5 satellite, are used to identify the boundaries of cloud systems, track their evolution, and determine the spatial and temporal scales of cloud thermodynamic forcing. The resulting quantitative, statistical description of monsoonal cloud systems is compared with simulated cloud systems in the NCAR CCM3 model.

Monsoonal clouds span a spectrum of spatial scales from smaller than  $25 \text{ km}^2$  to greater than  $10^7 \text{ km}^2$ . Atmospheric heating owing to precipitation and the cloud greenhouse effect, as well as surface cooling owing to cloud albedo, increases with the spatial scale of cloud systems. As a result, thermodynamic forcing of the monsoonal environment is dominated by the contribution from giant semi-permanent decks of overcast cloud that



persist for days to weeks. Embedded within such cloud decks are numerous rain cells reaching up to 1 million square-kilometers because deep convection organizes into clusters of narrow overturning cells attached to a broad stratiform region of precipitation. A relatively few such mesoscale convective systems are greater than  $10^5 \text{ km}^2$ , yet are responsible for up to 70% of monsoonal precipitation. In contrast, simulated cloud systems in the model gently precipitate throughout their duration and everywhere within their boundaries. The model lacks a process that acts to organize convection into mesoscale episodic structures.

Precipitation is the principal means by which particulate pollution is removed from the atmosphere. The effect of model biases in the distribution of precipitation is tested by integrating satellite precipitation measurements into the MATCH chemical transport model. Mesoscale convective systems in the equatorial Indian Ocean are a substantial barrier to the transport of aerosols from South Asia to the Southern Hemisphere. Using observations of the spatial coverage of precipitation in the model reduces the amount of South Asian aerosol transported to the remote Northern Hemisphere by more than a factor of 2 compared to a simulation using model derived precipitation.